THE MEASUREMENT OF PRESSURE.

THESIS

For the Degree of Bachelor of Science in School of Mechanical Engineering,
College of Engineering.

BY

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UNIVERSITY OF ILLINOIS.

1895.

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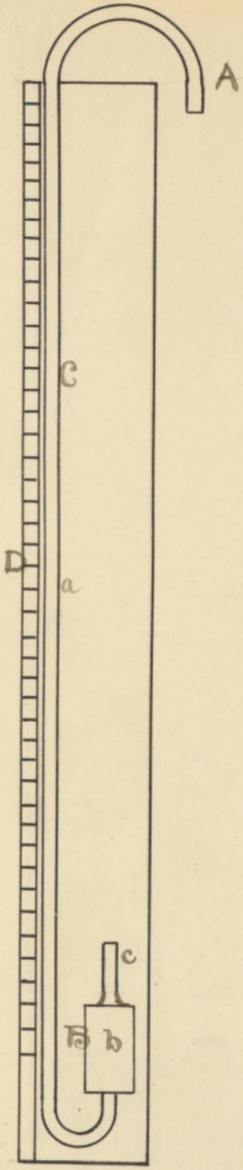
The Measurement of Pressure.

In all engineering work the measurement of pressure is very important, especially in the line of steam engineering. The object of this thesis is a discussion of the different methods employed for this purpose.

The term manometer is often used to designate any apparatus for measuring pressure but in this country the term is applied only to short columns of mercury or water, which are used to measure small pressures. The pressure thus measured is that above the atmosphere, thus if we desire absolute pressure we must add the atmospheric pressure to the manometer reading. This instrument may also be used to measure pressure below that of the atmosphere.

In the U tube manometer as in Fig. 2, Plate I the liquid is poured into the tube, where it will stand at a common level in both branches, at atmospheric pressure, but when pressure

Plate I.



Vaccuum Gage

Fig. 1.

and

Cistern Manometer.

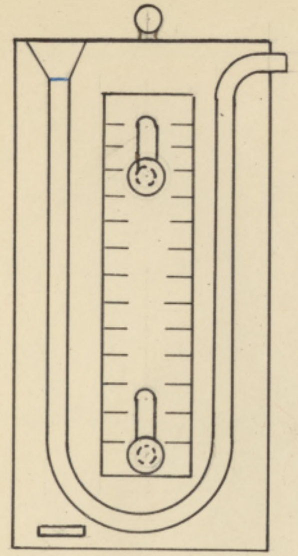


Fig 2

U tube Manometer.

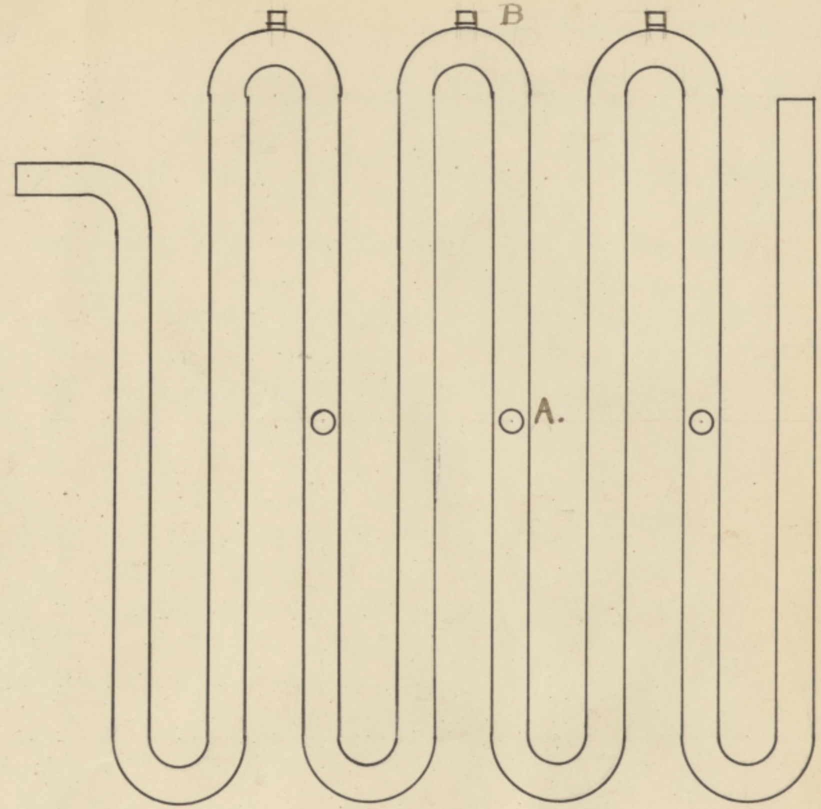


Fig. 3.

Improved Mercury Column.

is applied at the top of either tube, the liquid will be depressed in one and raised in the other branch. Thus the applied pressure is supporting a column of liquid equal in height to the difference in level of the liquid in the tubes. This may be reduced to pressure in pounds per square inch, as an inch of water at a temperature of 70°F. corresponds to a pressure of .033 lbs. per sq. in., while an inch of mercury is equal to .493 lbs per sq. inch.

If we assume p = atmospheric pressure and p_1 the absolute pressure to be measured expressed in inches of water or mercury, h = height of column on side of atmosphere, h_1 = height of column on side of pressure, then $p + h = p_1 + h_1$ and $p_1 - p = h - h_1$.

If we use two liquids of different densities this U shaped manometer becomes much more delicate and smaller differences of pressure may be measured.

In this case the heavier liquid is on the side of the smallest pressure. If d_1 = density of lighter liquid and d that of the heavier, h_1 and h the corresponding heights of columns, if all measurements are taken from lower surface of heavier liquid,

$p_1 + h d = p + h_1 d_1$, $p_1 - p = h_1 d_1 - h d_1$.

The liquids commonly used are water for the heavy and crude olive oil for the light one.

In Fig. 1. Plate I is shown a cistern manometer. This instrument is composed of a glass tube (a) connected with a cistern or vessel (b), the area of the cistern being much larger than that of tube (a). The cistern is filled with water or mercury and the pressure is applied at tube (c) forcing the liquid up the tube (a).

The pressure is represented by the difference in level between the liquid in the cistern and that in the glass tube. In graduating this instrument an allowance for the slight change in level of the liquid in the cistern must be made.

The term mercury column is applied to long columns, containing mercury, by means of which pressure may be measured. They are long, of uniform diameter, made of glass or steel. They are usually of the cistern type. The mercury column is the standard by which all spring gages are tested and calibrated, consequently it is of great importance that they should be as nearly correct as possible.

The bore of the tube and the cistern should be uniform so that one part of the tube will not hold more liquid than any other part. The graduations of the scale should be carefully made and the error determined. When readings are made, correction should be made for the expansion of the mercury and tube owing to increase of temperature. Correction should also be made for the action of capillarity of the tube. The glass tubes should always be kept clean or the mercury will cling to the sides of the tube, interfering with the readings. The cleaning is best done by drawing a clean piece of cotton through the tube. Great care must be taken not to scratch the glass as a fracture would then soon result. The variation in a column of mercury 50 feet high, caused by a change of temperature from freezing point to 70°F amounts to 4.32 inches of mercury equaling a pressure of 2.1 pounds per sq. in.

Pure mercury should be used or at least the exact specific gravity of that used should be determined. In long tubes errors in reading may occur from the oscillations of the mercury. So when readings are made the mercury should be perfectly at rest.

It has been very difficult to obtain mercury columns of sufficient height to measure high pressures, and when the Eiffel tower was built at the Paris Exposition, a great opportunity for measuring extremely high pressures was presented, and accordingly a mercury column of the following description was built upon it.

This column was 984 feet high giving a pressure of 400 atmospheres or 6000 lbs. As glass was not strong enough the tube was made of soft steel of about $\frac{1}{6}$" internal diameter, connected at the bottom of the tower with a reservoir containing mercury. By pumping water on the reservoir the mercury could be forced up the tube to the top of the tower. The column was placed in a slanting position for 197 ft, to the first platform, the tube being placed against the inclined plane of the rails of the elevator, an inclined stairway running beside it. Between the first and second platforms, about the same distance apart, the tube was fastened to the helicoidal staircases. As this staircase was in several sections not in the same plane, the tube was similarly divided and bends as it passes from one staircase to another, sufficient slope being allowed for the decent of the mercury when the pressure is reduced. From the second platform to the top the tube is arranged the same way following the two vertical staircases, so that the tube is accessible from top to bottom. The steel tube being opaque the level of the mercury could not be read directly so cocks with conical screws, each communicating with vertical glass tubes were arranged at equal distances, about every ten feet, parallel and alongside the tube. Each glass tube has a scale carefully marked off on polished wood which is selected on account of its being only slightly affected by change in temperature. It is adjusted by rubber bands to the framing, and leather rings compressed by a screw keep the cocks tight. When one of the cocks is opened the interior of the steel tube is placed in communication with the corresponding glass tube. As the mercury rises in the steel tube it passes into the glass tube and stands in the same level in each, the glass tube being placed vertical in each.

The head in any glass tube being limited to ten feet.

The scales are marked in meters and centimeters so that the head may be read with great accuracy. The tubes and scales are protected from the weather by hinged casings that open at will.

To obtain a given height or pressure the cock of the corresponding glass tube must be opened and the pump started, when the mercury reaches the cock it rises in the steel and glass tubes at the same time. By working the pump slowly the exact level may be attained but if too much a little water can be let out below, so as to lower the level of the mercury.

Communication is made from top to bottom by a telephone, the upper end of which may be moved from one height to another. If by mistake the mercury rises above the top of the glass, it returns to the reservoir by an overflow pipe.

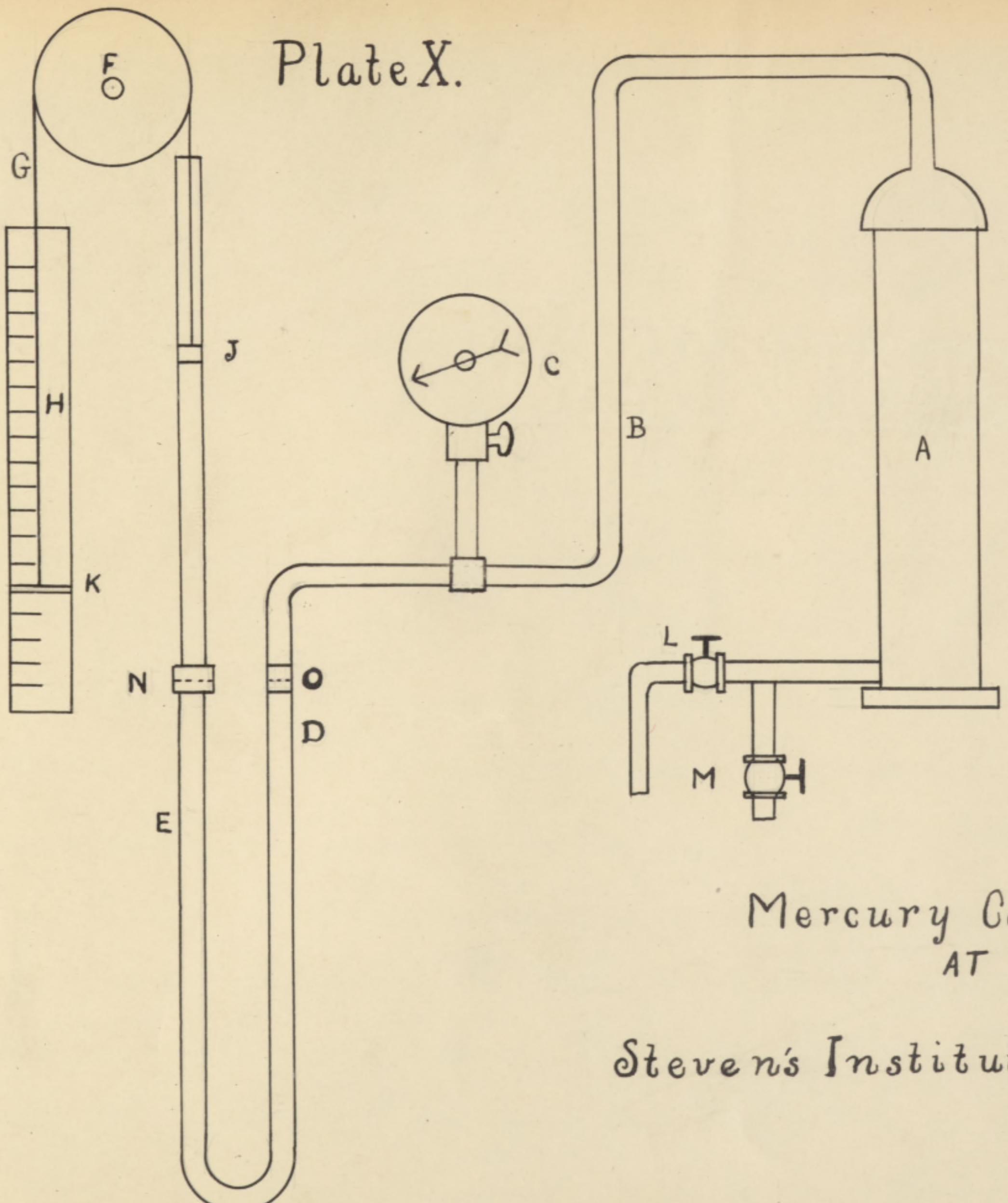
At the base of the tower is a laboratory containing the hydraulic force pump, the mercury reservoir, the telephone station and other accessories. Among these is a large gage connected with the mercury under pressure. It is marked to show the pressure in atmospheres and the numbers corresponding to the cocks up the tower. The operator is thus enabled to tell into which glass gage the mercury should rise for a given pressure and what cock should be opened. In order to calculate the pressure for a given height the mean temperature in the tube should be known. This is measured by the variation in the electric resistance communicated by the column to the telephone wire. In this Country one of the highest mercury columns was constructed by Mr. Edson, the manufacturer of the Edson Recording-gage, a description of which will be given later. This column was made to graduate four large gages. A $\frac{1}{4}$" inch heavy hydraulic pipe was run up one of the piers of the Brooklyn bridge, then in process of construction. The column was carried 265 feet above the point of observation, it being necessary to pipe up on the derrick to get the required height.

The manner of deviding the column so as to secure the desired pressures was to drill a $\frac{1}{16}$ inch hole every 10 feet and to plug these holes. Days of same temperature were selected for the experiments. The different levels were obtained by opening holes successively from the top, allowing the mercury to run out. The gages calibrated were of the Bourdon spring type with 10 inch dials. These gages were afterward used only as master gages.

The following is a description of a mercury column at The Steven's Institute of Technology. Plate X.

E and D are two wrought iron pipes ½" internal diameter containing mercury. A is an air reservoir from which compressed air is led through pipe B to the upper end of pipe D. When the air in A is not compressed the pressure of the atmosphere is in pipes E and D and the mercury is at the height indicated by the lines on the small glass discs N and O. J is an iron float resting on the mercury in pipe E. A silk string G crosses from this float over the pulley F and supports the index K, which slides along the scale H. L is the value for admitting water to reservoir A and M

Plate X.



Mercury Column
AT
Steven's Institute of Technology.

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is a valve for releasing the same. The method of operating the column is as follows;

The gage to be tested is placed at C. Water is admitted to reservoir A, causing compression of air above it. This compressed air acts on the gage and mercury in D causing mercury in D to fall and that in E to rise. The amount that the mercury is elevated in E is shown by the index K. The weight of air in D may be neglected for ordinary pressures.

In a tube designed by Mr. Francis Stevens the bore of each tube was the same so that the amount that the mercury was depressed in D would be the same as the amount it was elevated in E. But in the actual construction of this column, this is not necessary as a gage was taken to the makers and calibrated by a known column, and this gage is then placed at C and the scale H is graduated, then the gage is taken back to the makers and again calibrated and if it is the same it is assumed that the gage was right when the column was calibrated. After this second calibration of the gage, it is again placed at C and the scale at H is verified. This column involves no complicated mechanisms and the scale at H need be made only half as long as when a single tube is used.

It is usually difficult to build mercury columns high enough for pressures sometimes desired. The following is a description of a column, for high pressures, of small height. Fig. 3, Plate I. Mercury is poured in at holes A until level then A is plugged and some other liquid is poured in at B and B is plugged. Upon application of pressure to first column it is depressed a certain amount, the pressure is transmitted through the second liquid in the tops of the siphons and all the other columns are depressed the same provided they are all of uniform bore. On account of the weight of the upper liquid the sum of the differences in level in each siphon is too great by the amount of the pressure of the water. Thus the effect of the water must be deducted from the reading.

An equivalent height of a single mercury column is expressed by $nd\left(1 - \frac{1}{13.59}\right)$

where n = number of siphons

1 = specific gravity of water.

13.59 = specific gravity of mercury.

Any increase in temperature must be considered as it expands the contents of the tubes. The correction depends on the relative densities of the two liquids and the actual expansion of the mercury.

The above formula will give the equivalent height of a mercury column at any temperature if the specific gravities of the liquids at that temperature are substituted in the minus quantity of the formula. Thus if the upper liquid should lose in weight as much as does the mercury by the increase of temperature, the difference of level would remain the same. Thus if we select a liquid whose specific gravity multiplied into its coefficient of expansion equals the specific gravity of the mercury multiplied into its coefficient of expansion we may accomplish this result. Tetrachloride of tin very nearly fills these requirements and is sometimes used. Salt water and glycerin have also been used with good results. Trans A. S. M. E. Vol. II. P. 98.

The Metallic Spring Gage.—

For practical use the various forms of metallic spring gages have superseded mercury columns.

The first use of the principle upon which these gages depend was first made use of by Vidi, a Frenchman, in 1844, in the construction of the aneroid barometer which consisted of a closed vessel with elastic walls which were pressed in more or less as

Plate II.

Bourdon Steel Spring Gage

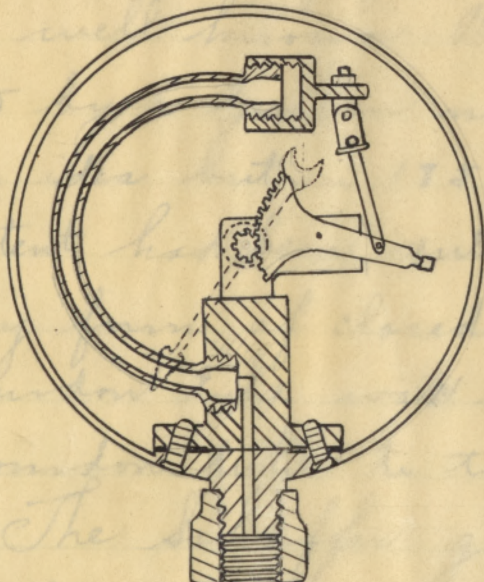

Fig. 1.

Lane Bourdon Spring Gage.

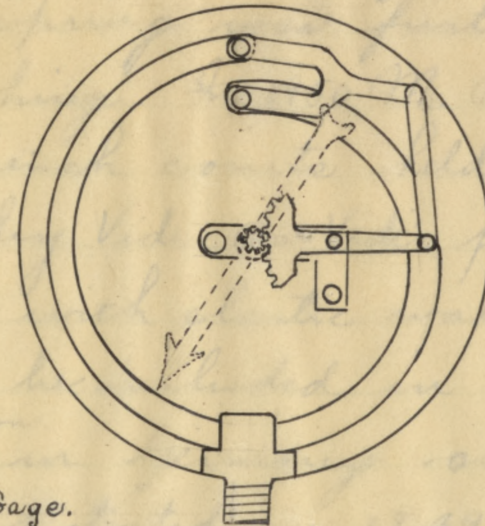

Fig. 3.

Diaphragm Gage.

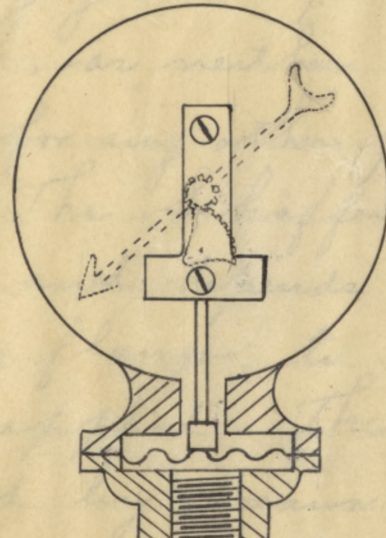

Fig. 2.

Types of Pressure Gages.

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the pressure was great or small.

The tube gage or barometer embodying the principle of the well known Bourdon spring was first constructed in 1845 by a German named Shinz. In 1850 M. Bourdon patented this idea but in 1859 the French courts held that Bourdon's patent had been anticipated by Vidi as Vidi's patent referred to any form of closed vessel with elastic walls and the Bourdon tube was held to be included in this. The Bourdon tube is to this day known in Germany as the Schinz.

The Schäffer gage was patented in 1849 and was the first steam gage, as neither Vidi or Shinz had ever used their instruments for any other purpose than barometric measurements. The Schäffer gage Fig II Plate II was patented in 1849, and depends on a corrugated steel diaphragm held between two flanges, to the under side of which the pressure is applied. The movement of the diaphragm is communicated by means of a rod to a toothed quadrant gearing into a pinion which carries a pointer on the dial. The mechanism multiplies the movement of the spring, so that a slight movement of it is shown on a greatly enlarged scale on the dial. A spiral spring takes up the slight amount of play which is unavoidable between pinion and quadrant. A very thin plate of silver or silvered copper protects the steel diaphragm from corrosion.

For some chemical purposes the diaphragm is made of platinum. Great care is necessary in the tempering and hardening of these diaphragms.

When made they are always subjected to numerous tests to ensure an ample margin of elasticity under the pressure for which it is intended.

A Schäffer gage with 6 inch dial graduated to 200# and intended for working pressure of 100# has a diameter of free part of diaphragm equal to $2\frac{1}{2}$ inches and total range of movement of center of diaphragm is

$\frac{1}{8}$ inch multiplied about 80 times on the dial. The limit of elasticity of such a diaphragm is about 300 pounds per sq. inch.

These gages are graduated as high as 400 pounds, and may be used up to 300 pounds working pressure. For gages registering smaller pressures the diaphragms are made of more flexible material as brass etc.

The other form of spring gage is called the Bourdon spring tube gage. The spring in this gage consists of a tube of elliptical cross section, bent in the form of a circle or the arc of a circle. One end of the tube is made stationary while the other end is free to move. This end is fastened to a lever which communicates to a multiplying mechanism similar to that of the Schäffer gage, so that a slight movement of the tube is greatly enlarged by the indication of the pointer on the dial.

Pressure is admitted to the inside of the tube Fig 1 Plate II. The pressure causes the tube to assume a more nearly circular cross section and the tube tends to straighten itself thus moving the free end and the multiplying mechanism. It has been determined by experiment that a tube of circular cross section will not tend to straighten itself when pressure is applied inside, as a tube of elliptical cross section will do.

These gages are usually made of copper alloy for ordinary pressures but for high pressures the tubes are made of steel. Steel is also used for gages intended for ammonia and other gases which have a corrosive effect upon copper. The best gages are very carefully made especially is this true of those gages intended for high pressures. Sometimes the steel tubes are made of drawn steel tubing, but the better class of gages are fitted with tube springs which are made solid and are bored out. For high pressure gases tubes which will safely stand pressures of 360 atmospheres without taking the slightest set, have been made. The diameter of the tubes being about $\frac{1}{2}$" with a wall thickness of $\frac{1}{16}$". After the tubes have been turned and bored, they are polished inside and out to remove every trace of tool marks and they are then microscopically examined by light reflected from a mirror, any tube showing marks or scratches being rejected as unfit for use. The good tubes are then carefully flattened and bent at a moderate heat, the proper performance of these operations requiring great skill and experience. Finally the tubes are hardened and tempered these operations requiring the same great care and skill. The tubes are then carefully examined and if satisfactory they are submitted to a series of tests. The tube is temporarily attached to a mechanism which is identical in its main features with that of the gage it is intended to fit. The tube is then given a pressure of 360 atmospheres for one hour or longer and if, when the pressure is removed, the pointer does not return to 0, the tube is rejected, as no tube is tempered twice.

The bursting strength of a tube like this is about 1000 atmospheres, but much stronger ones may be made as gages registering 4500 atmospheres per sq. inch have been successfully made and used.

When the tube has been proved acceptable it is attached to the carrier boss and the cap screwed on the free end of the tube, the metallic joint at both ends of the tube being made by means of a sharp edge projection which is turned on each end of the tube and beds itself into the material of the boss and cap. The multiplying mechanism is next fitted up, the parts being made in large quantities by special machinery, the gage is then fitted in its case and is attached to the test pump. The multiplying mechanism is adjusted so as to give the required movement to the pointer, the dial being temporarily fastened in the case, the scale is then marked out by comparison with two larger test gages.

The face is then fastened by three screws and the pointer fastened to the pinion spindle and the gage is again attached to the test pump and if satisfactory is ready for use.

In some factories the pressure is applied to the gage by means of oil, the oil left behind forming a protection from corrosion. For some purposes the tubes are tinned to prevent corrosion, marine gages especially are tinned outside and inside to prevent the action of the sea air.

For low pressures the common copper alloy tubes are accurate enough but for high pressures the steel tubes have great advantages above those of brass as regards accuracy, reliability and durability on account of the more perfect elasticity of the steel as against that of the brass.

It has been found by experiments that springs made of steel and then tempered have stood up better under work and retained their elasticity and original shape much better than those which are made hard by working and afterwards coiled or shaped into the required form. The reason seems to be that after the spring is formed into shape and heated for tempering, all the strain that has been put on the metal when the spring is being coiled is relieved by the heating and thus the metal is relieved of all internal strain when the spring is doing no work.

Since the indications of a gage vary with the temperature it follows that all gages should be kept under the same conditions of temperature as when graduated.

If steam is admitted directly to the spring, error is caused and the elasticity of the spring will soon be destroyed and the expansion of the spring will cause an error in the indication of the pressure, thus the pressure of any extremely hot or cold substance should be conveyed to the spring through some intermediate substance. This is accomplished by attaching a water siphon between the source of pressure and the gage. All gages should be attached to steam boilers in this manner.

Pressure should never be admitted suddenly as gages are often ruined by the shock of pressure entering suddenly.

Some leading manufacturers of gages are now making the multiplying mechanism of alloyed metal, so that none of the parts will corrode, thus the inaccuracy of the mechanism is lessened.

The accuracy of gages depends upon the perfect elasticity of the spring within working limits, the nicety and accuracy of the workmanship of the different parts, the accuracy of the graduation of the scale and last but not least the care, which is taken of them, while in use.

Gages of greater accuracy than those commonly used are carefully made and used only for comparing and standardizing other gages. These are called test gages and are very carefully used. Test gages are preferably of the duplex type, that is, two complete gage works fitted in one case to indicate on one dial, thus checking each other.

In Indicator tests at the Brooklyn Navy Yard it was found impossible to find a standard test gage which would not vary in indications of the same pressure, when being under tension for some time the spring became fatigued, the amount of fatigue depending upon the intensity of the tension and the length of time it was maintained. This caused the indications to be higher than they should be. The fatigue was not permanent and the spring returned to its normal condition after rest. In these tests the pressure gages were replaced by mercury columns.

A safety appliance for high pressure gas gages has been devised by an Englishman as follows; The Bourdon spring is filled with a fluid like glycerin, thus preventing the gas from entering the instrument. This liquid is retained in the tube by a piston located in a strong chamber attached to the inlet. The gas in this case exerts its force on the piston which forces more of the fluid into the tube. If the tube should give way this piston would close the opening and stop the escaping gas. The viscosity of the fluid tends to arrest sudden movement and consequently there is less wear on the toothed gearing and the strain does not come on the tube so suddenly.

Some Bourdon spring gages are so constructed that when the pressure is released all the liquid in the tube will run down so that if exposed to the cold it will not freeze and burst the tube. One of these gages is illustrated in Fig. 3, Plate II.

There is a gage called Shaw's mercury gage which seems to be a very accurate indicator of pressure. The only moving part of this gage is a double headed piston. The one end of this piston is small and is exposed to the pressure that is to be measured, the other end is large and

and fits in a reservoir containing mercury. When pressure is applied to the smaller end it is forced upward thus forcing the mercury, above the large end, upwards until the pressure of the mercury on the large end just balances the pressure upon the smaller end. When the piston is forced upward it forces some of the mercury up a glass tube. This tube is graduated so that the height to which the mercury rises in the tube indicates the pressure at the small end of the piston. This gage is simple and is said to be very accurate.

A gage in which the elastic medium is air, is the invention of an Englishman named Allan. In this gage the index is formed of a column of water in a graduated glass tube. This water is acted on at one end by the pressure while above it is a body of air with no means of escape. When the boiler is cold, the air is at atmospheric pressure, but when steam is raised the water is forced upward and the air is compressed. If the whole of the air were contained in a parallel tube, the variations of pressure would grow steadily less for equal increments of pressure, and at high pressure the scale would be very minutely divided, but this is overcome by a tapered vessel of such form that equal increments of pressure cause equal rises in water level. Thus we have a gage spring that cannot be corroded strained or deformed, and which needs no multiplying gear. In this gage the elasticity of the spring is perfect, and the variation of temperature will have but small effect on it as the air may be renewed at any time, or a correction can easily be made by a glance at a thermometer.

Recording gages are those which keep a record of the pressure at all times of the day. They are of numerous types but the object of all is the same, that is to make a record of pressures so that at a glance it can be told what pressure was on the boiler at any past time.

This is accomplished by placing a marking pen on the end of the pointer which moves either upward and downward or in the arc of a circle, the movement of this pen being traced upon a chart, which is slowly drawn along by a clock work, which usually makes one revolution each twenty four hours.

The Edson recording gage is a good example of this class. It is actuated by a corrugated diaphragm of tempered steel, which by a peculiar mechanism makes a mark exactly vertical, and at the same time sweeps a regular gage pointer through the arc of a circle graduated to pounds per sq. inch. The spring arm carrying the pencil keeps the point at all times against the paper while appropriate clockwork moves the paper from left to right, to correspond to the hours of the day or night during a period of 24 hours.

One peculiarity of the Edson gage is that the pressure on its steel diaphragm on one hand and the resistance of the diaphragm on the other contribute greatly to the steadiness of motion as the work to move the diaphragm is so great compared with the recording that the work for the latter is comparatively nothing, the steadiness of the pencil line showing the value of this feature. An alarm is arranged to sound at any desired pressure.

There are three recording gages made by W. H. and E. H. Bristol, known as the Bristol Recording gages that deserve special mention.

For ordinary pressures a tube spring is used as is shown in Fig. 1, Plate III. The pressure enters the sinuous tube A tending to straighten and elongate it, this tendency is resisted by the flexible strip B which is joined to tube A at the bends, converting the tendency to elongate into a multiplied lateral motion. The inking pointer is attached directly to the end of the pressure tube and

Plate III

THE BRISTOL RECORDING GAGES.

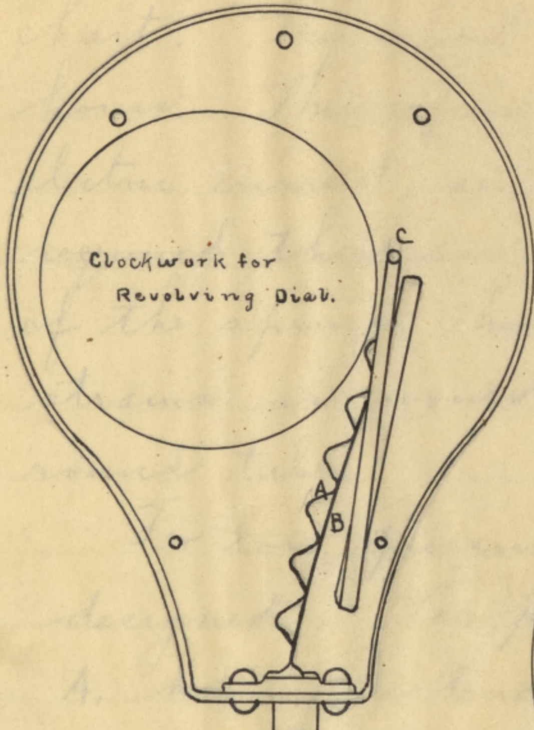


Fig. 1.

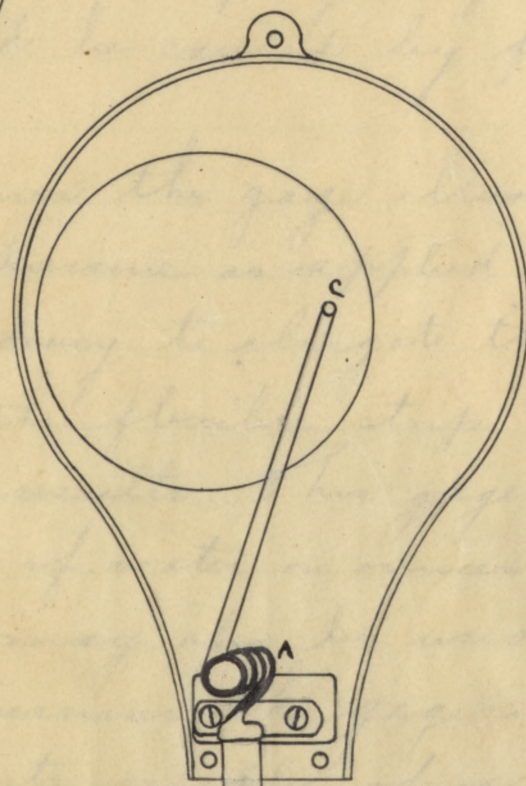


Fig. 2.

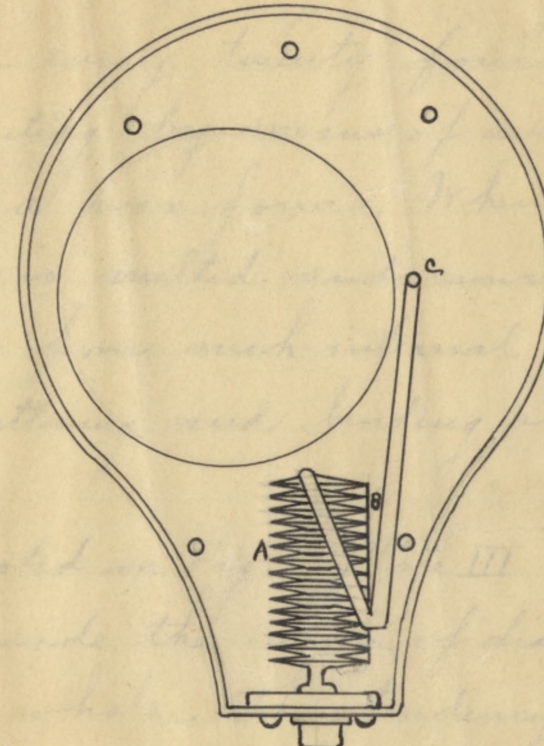


Fig. 3.

Clyde R. Carmack.

records the fluctuations of pressure on a uniformly revolving chart. This chart makes a revolution every twenty four hours. This spring is made by depositing by means of an electric current, an alloy of nickel upon a wax form. When the required thickness is acquired the wax is melted and runs out of the spring. Thus the spring is free from such internal strains as would be caused by flattening and bending a round tube.

For low pressures the gage illustrated in Fig. 3, Plate III is designed. The pressure is applied inside the series of diaphragms A, having a tendency to elongate the whole. This tendency is resisted by the flexible strip B and a multiplied lateral motion results. This gage is graduated to tenths of inches head of water or ounces per square inch. This form of tube may also be used as a vacuum gage.

For high pressures the gage in Fig. 2, Plate III is made. The spring consists simply of a Bourdon tube of flattened cross section wound into a small helical form of four complete revolutions. One end of the tube is fastened to a bracket with an opening for the pipe communicating to the gage, and on the free end of the tube is fastened the pen arm. The diameter of the helical spring is only one inch, so the movement of the spring is small but the motion of the pointer is quite large. By varying the thickness of the metal, the cross section, and the number of revolutions of the tube a helix adapted to almost any desired range of pressure may be obtained.

These gages make the record on similar charts, and are free from one great source of error, that is there is no complicated multiplying mechanism necessary.

It is claimed by the makers that there is very little difficulty in making springs of uniform qualities.

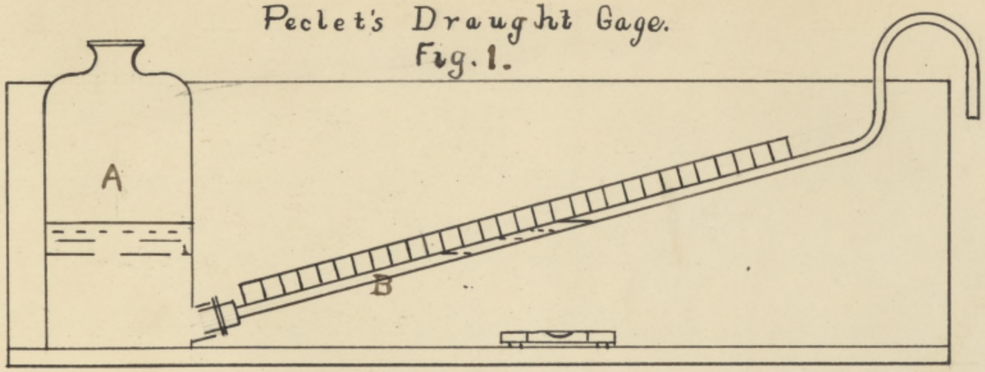
There are numerous other forms of recording gages using the common Bourdon and diaphragm springs.

The recording feature is valuable in many ways, as to show pressure in case of fire, increases attention of employes, as they know that a record is being kept and any negligence on their part will be shown. the detection of water hammer and obstructions in pipes, or of excessive pressures etc.

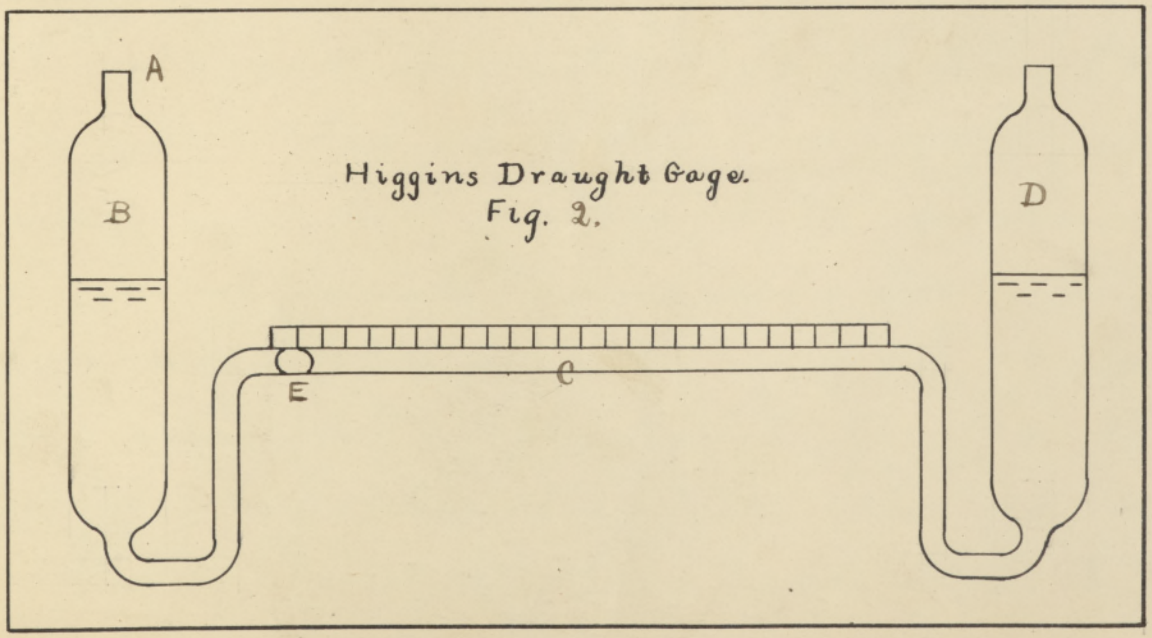
In many cases it is desired to determine the amount of very small pressures. A very common method is by means of a manometer as in Fig. 2, Plate I. But when very accurate measurements are desired various means are resorted to to multiply the motion of the water in the gage. In Fig. 1, Plate XI, is illustrated one method of doing this. When the liquid rises or falls a short distance in vessel A the level in the tube B moves a greater distance, therefore smaller differences in level may be measured. In Fig. 2, Plate XI is another device to obtain the same result. The pressure is conveyed by a rubber tube to the neck

Plate XI.

Peclet's Draught Gage.
Fig. 1.



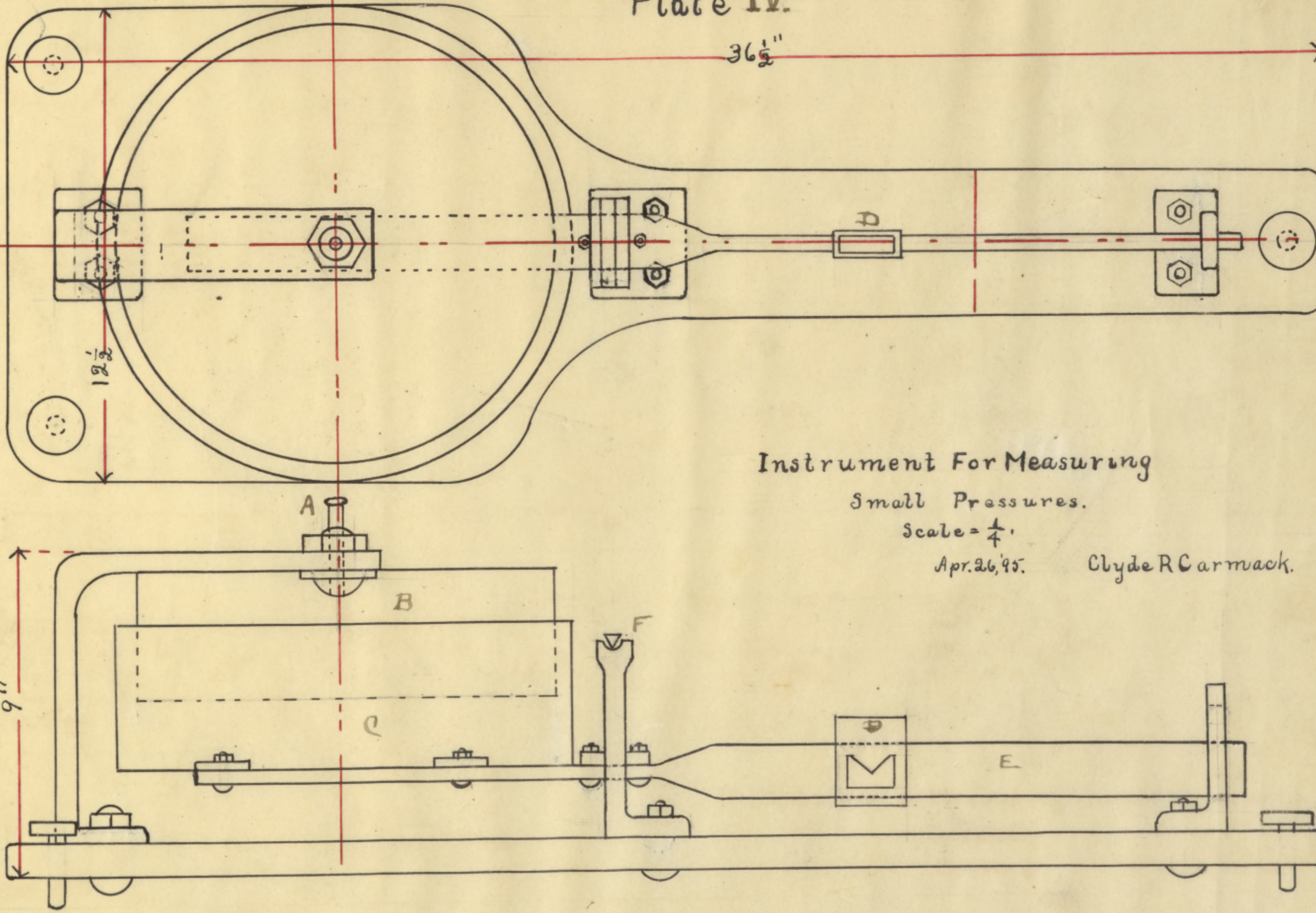
Higgins Draught Gage.
Fig. 2.



A of the vessel B. This vessel the tube C and the vessel D are filled with water, at a common level in both vessels. The area of the tube C is much smaller than that of the vessels. There is an air bubble in tube C at E. Now when pressure is admitted at A the level of the liquid in B is forced downward and the liquid is forced through the tube into vessel D carrying the air bubble E. Thus the movement is proportional to the difference in area of the vessels and the tube. If we assume the area of the vessel as eight times that of the tube, then the air bubble will travel eight times as far as the level of water will fall in vessel B. Sometimes colored liquids are used in the two vessels and the place where the liquids come together is used instead of an air bubble to denote the movement of the liquid through the tube.

As a means of determining the value of very small pressures the instrument shown in Plate IV was

Plate IV.



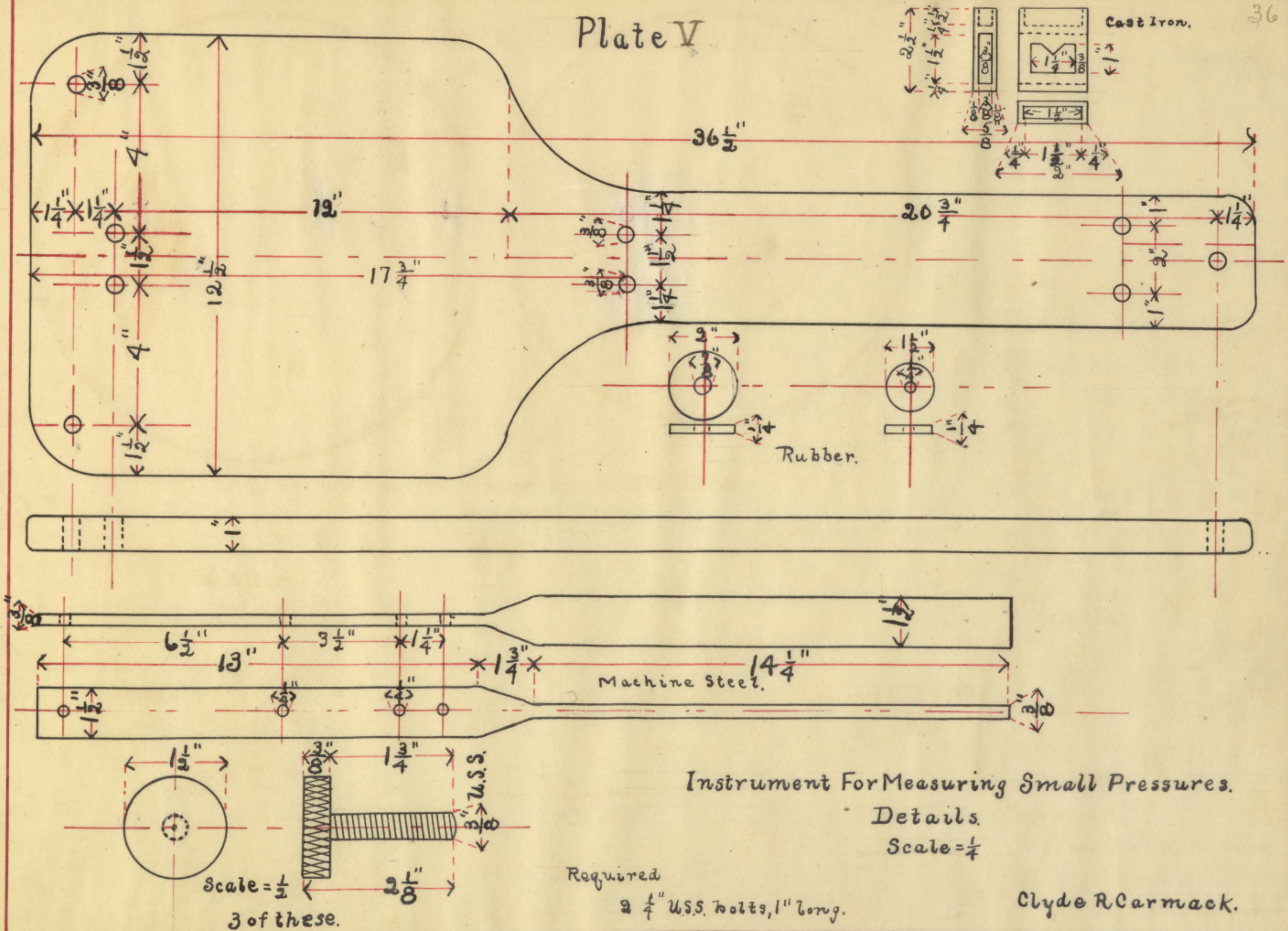
Instrument For Measuring

Small Pressures.

Scale = $\frac{1}{4}$.

Apr. 26, '95. Clyde R Carmack.

Plate V



Instrument For Measuring Small Pressures.

Details.

Scale = 1/4

Required

2 1/4" U.S.S. bolts, 1" long.

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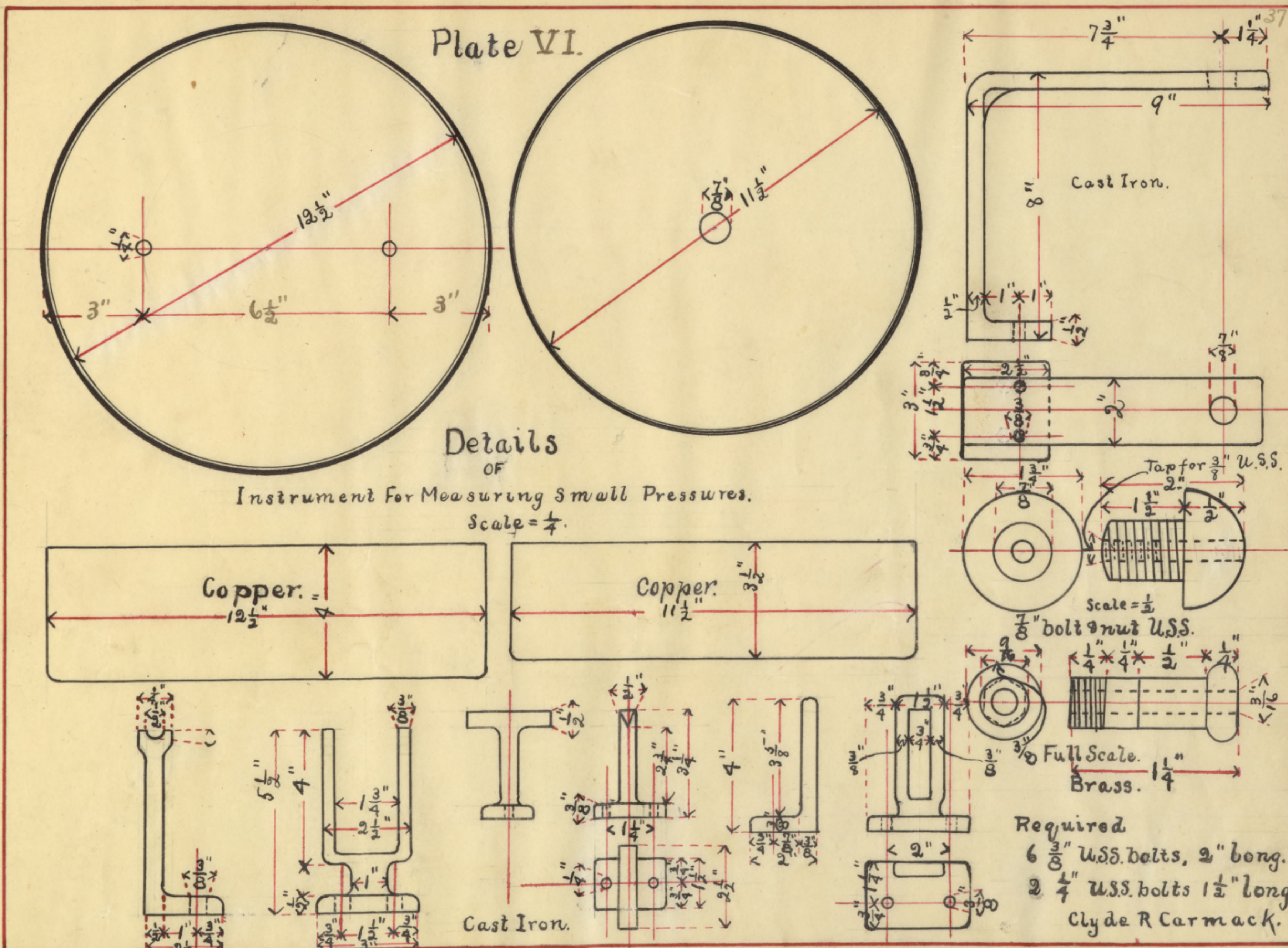
Plate VI.
Details of Instrument For Measuring Small Pressures.
Scale = 1/4.
Copper.
Copper.
Cast Iron.
Cast Iron.
Tap for 3/8" U.S.S.
Scale = 1/2
7/8" bolt & nut U.S.S.
Full Scale.
Brass.
Required
6 3/8" U.S.S. bolts, 2" long.
2 1/4" U.S.S. bolts 1 1/2" long.
Clyde R Carmack.
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designed by the writer. A device very similar to this was used by Prof. L. P. Breckenridge in his engineering work some years ago. It consists of applying a small pressure per square inch upon a large known area, and then as the area is known the pressure may be determined very accurately.

The pressure is admitted through the tube A to the vessel B. The vessel C is filled about two thirds full of water and equilibrium is attained by means of the sliding weight D. When pressure is admitted the vessel C is forced downward. The slider D is then moved until equilibrium is again attained. The scale on the arm E is graduated so that pounds per square inch may be read off directly.

The vessel C and arm E balance on the knife edge F.

Plates V and VI are detailed drawings of this instrument. It may be so designed to measure vaccuum or very small pressures.

Fig. 1. Plate I shows a cistern manometer, designed for a vaccuum gage. The vaccuum is connected at A, and the pressure of the atmosphere forces the mercury from the

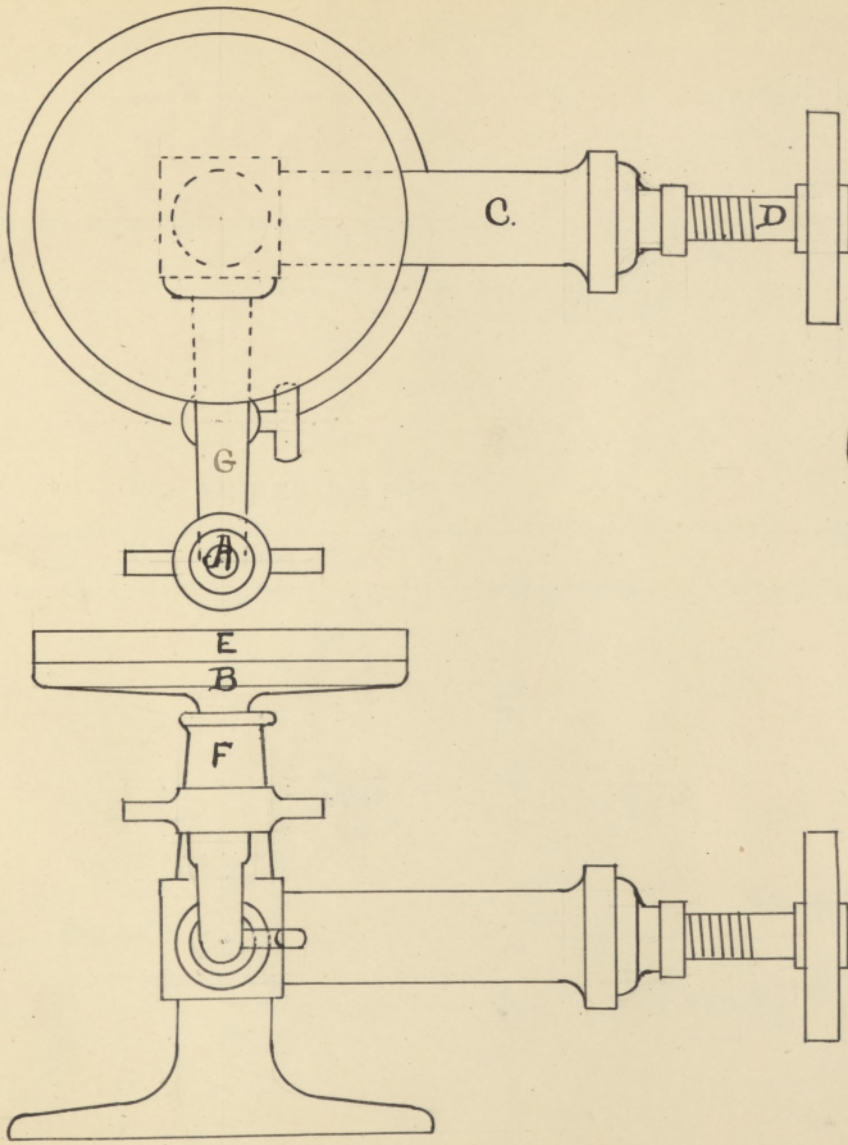
cistern B up the tube C indicating the vaccuum in inches of mercury on the scale D.

All spring gages are unreliable unless frequently tested as otherwise we cannot know what the effect of the constant use of the gage is, and how the constant expansion and contraction of the spring may have changed it.

The usual methods of testing are comparison with test gages, the same pressure being applied to the test gage and the one to be tested by means of a pump, and by the application of a known dead weight pressure per square inch.

An instrument of the latter type is illustrated in Plate VII. The gage is placed at A and securely fastened, then known weights E are placed successively upon the platform B. F is a hollow cylinder in which the lower end of B works as a piston. This cylinder

Plate VII.



Crosby Gage Tester.

Scale = $\frac{1}{2}$.

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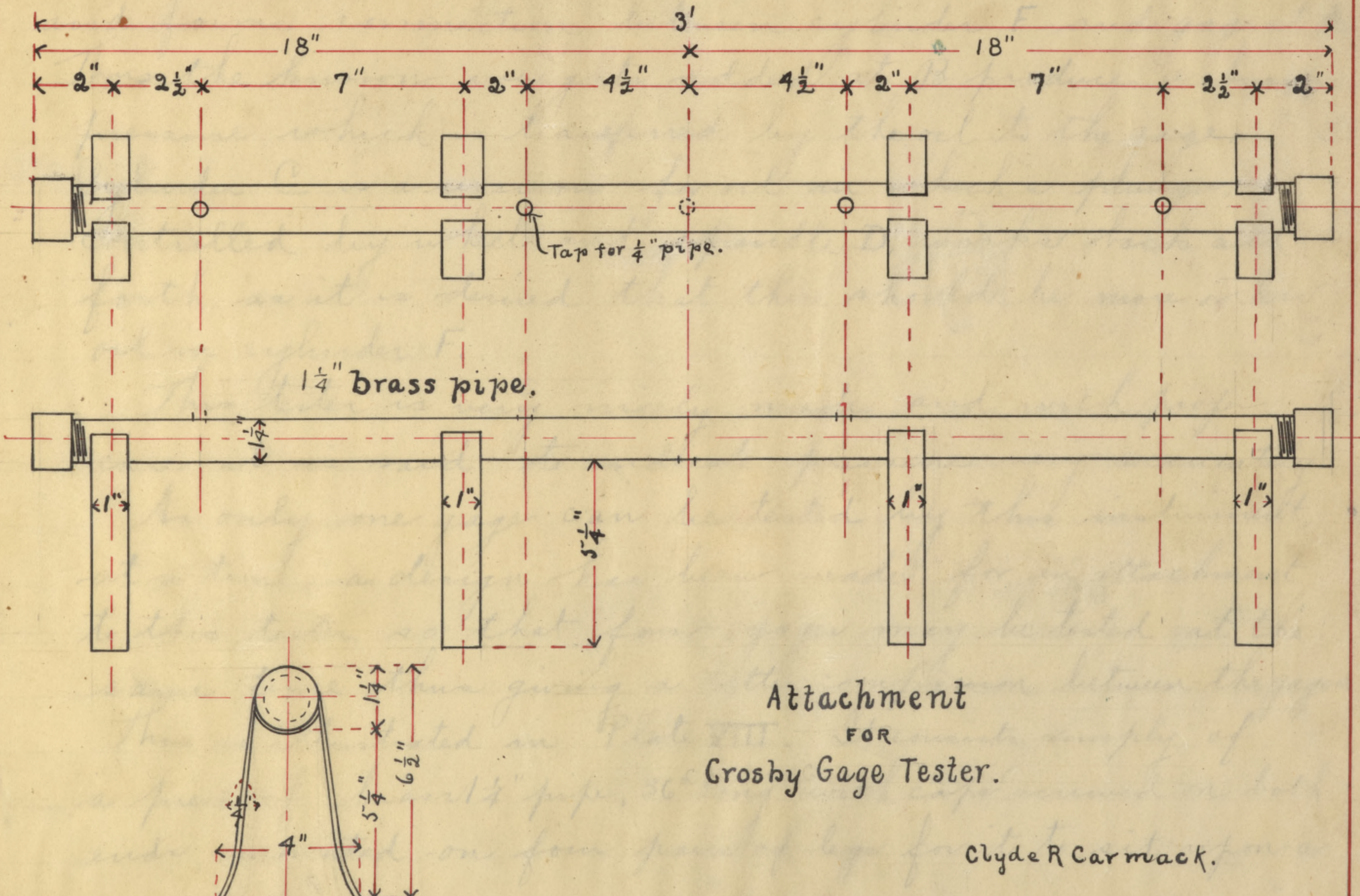
Plate VIII.



Attachment
FOR
Crosby Gage Tester.

Clyde R Carmack.

is filled with oil, glycerin preferred. The tube G is hollow and forms connection between cylinder F and gage at A. Thus the known weights added at B produce a known pressure which is transferred by the oil to the gage. Cylinder C is a reservoir for oil in which a plunger, controlled by wheel and spindle D, works back and forth as it is desired that there should be more or less oil in cylinder F.

This tester is very nicely made and with proper care it is said to indicate pressure very accurately.

As only one gage can be tested by this instrument at a time, a design has been made for an attachment to this tester so that four gages may be tested at the same time thus giving a better comparison between the gages. This is illustrated in Plate VIII. It consists simply of a piece of brass 1¼" pipe, 36" long with caps screwed on both ends, mounted on four pairs of legs for it to sit upon a table or platform to which the tester is fastened. In the middle is a hole tapped for $\frac{1}{4}$" pipe connections. This is connected with the tester in the same way that a gage would be fastened. On the upper side of the attachment are tapped four holes, where gages may be attached. Then the oil would be forced into the four gages at once and the errors noted.

Tests were made with the gage tester to see whether thick or thin oil should be used in it. The readings are given in table I. For low pressures thin oil is quite satisfactory but for high pressures it is very difficult to keep tight joints, so the oil will not leak out. While the thick oil will not leak out at the joints so much. The readings in Table I are practically the same especially for ordinary pressures.

Having had some trouble in regard to the readings of different gages an apparatus was designed as in Plate IX

Table I.

Experiment of using thick and thin oil in gage tester.

Thin Oil.

Wt. on tester	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Gage Reading Up	3	8.5	13.5	18	23	28	32.5	38	42	47	52	56	60	66	71.5	76	81.5	86	91.5	96
" " Down	3	9	13.5	18	23	28	33	38	43	48		57	62	68		78	83	87		97
" " Average	3	8.7	13.5	18	23	28	32.7	38	42.5	47.5	52	56.5	61	67	71.5	77	82.2	86.5	91.5	96.5
Wt on Tester lbs □"	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195
Gage Reading Up	101	104	110	115	120	122.5	128	134	138	142.5	149	154	158	161	165		174			
" " Down			110	115		124				144		154			166		176			
" " Average	101	104	110	115	120	123.7	128	134	138	143.7	149	154.	158	161.	165.5	175	175			

Thick Oil

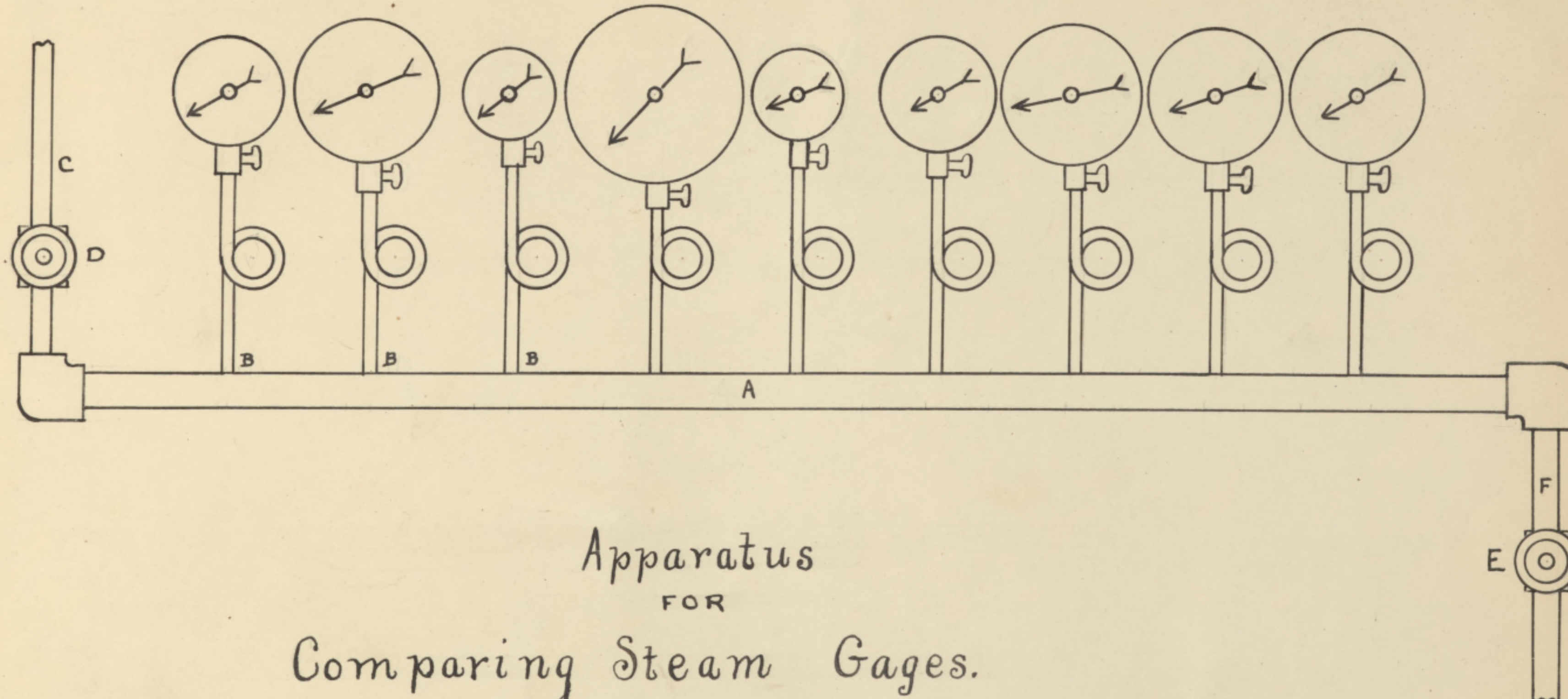
Wt. on tester # per □"	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Gage Up		8.5	13.5	18	23	28	33	38	42	47	52	56	62	66	72	77	81	86.5	91	96
" Down		8.5	13.5	18	23	28	33	37	42	47	52	57	62	67	72	77	82.5	87	92	97
" Average		8.5	13.5	18	23	28	33	37.5	42	47	52	56.5	62	66.5	72	77	81.7	86.7	91.5	96.5
Wt. on Tester	100	105	110	115	120	125	130	135	140	145	150	155	160	165	175	180	185	190	195	200
Gage Up	101	106	111	115	119.5	123.5	128.5	131.5	138	144	148.5	153.5	158.5	162.5	172	177	182	186	191	195
Down	102	106.5	111	116	120.5	125	130	135	139	144	149.5	154	158.5	163.5	173.5	178	183	187	192	
Average	101.5	106.2	111	115.5	120	124.2	129.2	132.2	138.5	144	149	153.7	158.5	163	172.7	177.5	182.5	186.5	191.5	

Calibration of Crosby Gage 328936.

Feb. 27, 1895.

Clyde R. Carmack.

Plate IX.



Apparatus
FOR
Comparing Steam Gages.

Clyde R. Carmack.

to make a comparison of gages under the same pressure. A piece of gaspipe A was tapped for standard gage connections in nine places. Siphons were screwed in and gages attached. Connection was made to the boiler through pipe C and pressure was controlled by valves D and E at the entrance and exhaust ends of the apparatus. Live steam entered through pipe C and when condensed was carried away through pipe F. The tables II III & IV show the results obtained by comparison of the different gages in use around the University.

In these tests a new gage that had never been used was placed at one end and considered as standard, and readings were made every five pounds, then as the new gage read five pounds in advance every time the readings of the other gages were noted and we could determine about what the error of each gage was by comparison with a new one when under actual conditions, and also the difference in readings

Table II.

Gage	READINGS.									
Utica 114164	0	5.5	10.2	15.5	21	25.5	31	36	41.5	46
Crosby 291197	5	13	18	23	29	33	38	42	47	52
Crosby 328938	0	10	14.5	18.5	24	27	33	38	44	47
Ashcroft 6220	3	15	20	25	32	36	42	48	53	59
Crosby 291198	2	10	15	20	25	30	36	41	45	50
Crosby 328936	4	12	17	20.5	25	30	35	40	44	49
Crosby (old)	5	14	18	22	26	31	35	40	45	50
Fisher Gov. Co	6	10	15.5	20	24.5	30	35.5	41	46	50.5
Utica 114165	0	5	10	15	20	25	30	35	40	45.

Table III.

Gage	READINGS.																		
Utica 114165.	0	5	10	15	20	25	30	35	40	45	50	55	60						
Crosby Eng. Bl	0	8	15	20	28	32	37	42	47	52	58	63	68	70	64	78	83	89	90
Crosby Nat. Hist. Bld.	0	9	15	20	26	30	35	41	46	51	55	60	65	68	71	77	82	87	88
Crosby 291198.	3	9	14	19	25	30	35	41	45	50	55	60	65	66	69	75	80	84	85
Bourdon 186297.	2	10	15	20	25	30	35	40	45	50	55	60	65	66	69	73	79	84	85
Crosby (old)	5	10	15	21	26	31	35	40	46	50	55	60	65	66	71	74	80	86	86
Crosby 291197.	5	11	16	21	25	31	36	41	46	50	55	60	65	66	70	75	81	85	86
Crosby 328939.	0	8	14	18	23	28	34	38	44	48	54	58	64	65	70	75	80	85	86
Crosby 328938	0	7	12	17	22	27	32	37	43	47	53	58	62	62	68	72	78	83	84

Comparison of Steam Gages.

Clyde R. Carmack.

Table III.

Name and No. Of Gage.	READINGS.																															
	Up																	Down.														
Crosby Test Gage.	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
Eng. Build. Gage.	0	7	12	18	22	27	34	39	44	49	55	60	65	71	76	82	87	82	77	72	67	62	56	50	45	40	35	29	24	18	14	8
Nat. Hist. Bld. Gage.	0	7	12	18	23	28	33	39	43	49	55	60	65	70	75	81	86	82	77	71	66	61	55	50	45	40	35	29	24	18	14	9
Crosby 291 198	3	8	13	18	23	28	34	39	44	49	54	58	64	68	74	78	83	78	74	68	64	58	54	48	43	39	34	28	23	17	14	9
Crosby Test 309 540.	0	2	9	14	19	23	28	33	38	44	48	53	59	64	69	74	79	74	70	64	59	54	49	44	39	34	29	24	19	14	9	3
Utica 114 165.	0	4.5	9.5	14.5	19.5	24	29	34	39	44.5	49.5	54.5	60	—	—	—	—	—	—	—	—	55	50	44.5	39.5	35	29.5	25	19	14	9.5	4.5
Crosby 291197.	6	10	15	20	25	31	36	41	45	50	55	60	65	70	75	80	85	80	75	70	65	60	55	50	45	40	37	30	25	19	15	10
Crosby 328939.	0	8	12	18	23	28	34	38	43	48	53	57	63	68	73	78	84	78	74	68	62	58	53	47	42	37	34	27	23	17	12	7
Gage on Steam Main at Boiler.	0	8	13	19	24	30	35	40	45	50	55	60	64	68	74	78	84	78	74	68	62	58	54	48	43	38	34	28	23	17	12	7

Comparison of Steam Gages.

U of I

Apr. 6. 1895.

Crosby Test Gage used as standard.

Clyde R. Carmack.

Table IV.

Comparison of Steam Gages.

Make of Gage.	Number.	Readings.										
Utica	114164	0	5.5	10.5	15.7	21	25.5	31	36	41.2	46	49.2
Crosby	291197	5	11	15.5	20.5	26	31	36	41	46	51	54
Crosby	328938	0	6.5	12	17	22	27	32	36	42	47	50
Ashcroft	6220	6	13.5	19	24	30	35	40.5	46	53	58	61
Crosby	291198	4	8.5	13	18	24	29	34	39	44	50	52
Crosby	328936	7	10	15	19	24	29	34	39	44	49	52
Crosby	old	5	10	15	20	25	30	35	40	45	50	53
Fisher Gov. Co		2	9	14.5	19.5	25	30	35	40	45	50	52
Utica	114165	0	5	10	15	20	25	30	35	40	45	48

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Table V.

Gage.	READINGS.																											
Utica 114165	0	5	10	15	20	25	30	35	40	45	50	55	60															
Crosby. Eng. Bld.	0	6	16	20	25	30	35	40	46	50	56	62	67	71	76	81	85	91	96	102	107	112	117	123	128	132	136	143
Crosby. Nat. Hist. Bld	2	10	18	23	26	31	35	40	46	50	56	61	66	70	75	80	84	90	95	100	106	111	115	121	125	131	135	142
Crosby. 291198	3	10	15	21	26	31	35	40	45	50	55	60	64	69	73	77	81	87	92	97	104	107	111	118	123	127	132	138
Crosby. 328938	0	8	14	18	23	28	32	36	42	46	51	56	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135
Crosby Test	2	9	15	20	25	29	35	38	45	50	54	60	65	66	74	78	84	89	94	99	104	109	114	120	124	129	135	140
Aschroft 6220	10	16	24	30	35	40	45	49	55	60	65	72	78	82	90	94	101	107	113	120	128	133	139	147	155	160	168	175
Crosby 328939	0	10	18	23	27	32	36	40	45	50	55	60	65	67	74	78	84	88	93	97	104	108	113	118	124	128	133	138
Utica 114164	0	5.5	11	21	21	26	31	36	41	46																		

Comparison of Steam Gages.

Readings Show that Aschroft No 6220 is unfit for use as spring seems too weak.

U of I. 1895.

Clyde R. Carmack.

of all the gages that were being tested.

The indicator is an instrument for measuring the pressure, at different parts of the stroke, in the cylinder of a steam engine but as a discussion of the indicator is of itself a subject for an entire thesis it will not be discussed here.

The original work done on this thesis is—, examination of different types of gages, manometers, etc., correction and repair of those now in use, design of instrument for measuring small pressures, design of manometer, design of attachment for Crosby gage tester, experimental work with gage tester, experimental work in comparison of steam gages including all results given in tables.

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